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TECHNICAL REPORT
AFFECTED ENVIRONMENT

SUPPLEMENT TO FLOOD CONTROL

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PROGRAM

SUPPLEMENT TO FLOOD CONTROL

This Supplement to the Affected Environment Technical Report for Flood Control contains information on regulatory context for flood control and levee system integrity and maintenance. Table S-1 lists the federal and state statutes, orders, and regulations affecting flood control. The following section discusses levee stability and mechanisms of damage or failure. A glossary of terms is found at the end of this Supplement.

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Date	Statute/Order/ Regulation	Federal/ State	Provisions Affecting Flood Control
1850	Federal Swamp and Overflow Act	Federal	Provided for the title of wetlands to be transferred from the federal government to the states.
1861	Reclamation District Act	State	Allowed drainage of Delta lands and construction of sturdier levees.
1902	Federal Reclamation Act	Federal	Allowed the development of irrigated lands in the western United States.
1911	Reclamation Board	State	Created by the California Legislature to implement a comprehensive flood control plan for the Sacramento and San Joaquin rivers.
1917	Flood Control Act	Federal	Authorized the Sacramento River Flood Control Project, consisting of a comprehensive system of levees, overflow weirs, outfall gates, pumping plants, leveed bypass floodways, and overbank floodway areas. Operation and maintenance is the responsibility of the State of California.
1930	State Water Plan	State	Plans transfer of northern California water throughout the Central Valley (becomes Central Valley Project).
1933	Central Valley Project Act	Federal	Provided for the construction, operation, and maintenance of a system of works, comprising essentially "Shasta Dam and Reservoir, Contra Costa Canal, Delta Cross Channel, Delta-Mendota Canal, Friant Dam and Reservoir, Madera Canal, Friant-Kern Canal, facilities for generation and transmission of electric energy, and such other units as may be from time to time added..."
1948	House Resolution 618, 80th Congress, 2nd Session	Federal	The Department of the Interior was authorized to investigate the feasibility and justify the means for conservation, maintenance, and use of the fresh waters of the Sacramento and San Joaquin rivers.
1948	Senate Committee on Public Works	Federal	Board of Engineers for Rivers and Harbors was directed to review reports on the Sacramento River for navigation and flood control to determine whether it was advisable to modify existing projects to reduce the tidal prism to a minimum.
1950	Section 205 of the Flood Control Act	Federal	The Secretary of the Army was authorized and directed to prepare preliminary examinations and surveys for flood control and allied purposes, including channel and major drainage improvements, and floods aggravated by or due to wind or tidal effects in the Sacramento and San Joaquin River Delta areas.
1960	State Water Resources Development Bond Act	State	Authorized the sale of $1.75 million of bonds to assist in financing initial facilities of the SWP. Included provisions for master levees, control structures, channel improvements, and appurtenant facilities in the Delta for water conservation, water supply, transfer of water, flood and salinity control, and related functions.
1973	Delta Levee Maintenance Subvention Program	State	Required DWR to develop criteria. The maintenance and improvement based on qualifying plans. Requires DWR to annually inspect planned improvement of non-project.
		–	Delta levees. Established method for reimbursing some agency costs of levee maintenance or improvement based on qualifying plans. Required DWR to annually inspect planned improvement and maintenance work, and to report inspections to the Reclamation Board for decision regarding cost-sharing certification. Allowed advances from DWR to local agencies for such work, and allows DWR to establish and conduct planned routine maintenance in "maintenance areas." Required applicants to first file for federal disaster assistance whenever eligible.

Table S-1. Federal and State Statutes, Orders, and Regulations Affecting Flood Control (Page 1 of 2)

Date	Statute/Order/ Regulation	Federal/ State	Provisions Affecting Flood Control
1976	California Water Code Sections 12225, 12226, and 1227	State	Section 12225 approved the levee improvement (Nejedly-Mobley Delta Levees Act) plan set forth in Bulletin 192 of DWR as a conceptual plan to guide the formulation of projects to preserve Delta levee system integrity Section 12226 required DWR to report to the Legislature regarding Delta levee improvements, and allowed DWR to prepare plans for Delta levee improvements and to proceed with pilot improvement studies. Section 12227 states the name of the chapter as the "Nejedly-Mobley Delta Levees Act."
1988	Delta Flood Protection Act (Senate Bill 34)	State	Created the Special Flood Control (California Water Code Sections 12310-12316; amendments to §§ 12980-12993) project program for the eight western Delta islands (Bethel, Bradford, Holland, Hotchkiss, Jersey, Sherman, Twitchell, and Webb) and the communities of Thornton and Walnut Grove. It amended the Delta Levee Maintenance Subvention Program established in 1973 to provide $120 million in State financial assistance to local districts over a ten-year period for maintaining and improving non-project Delta levees. Created a special account in the California Water Fund for appropriation by the Legislature to DWR for fish, wildlife, and water quality mitigation in the Delta, Suisun Marsh, and San Francisco Bay.
1991	Senate Bill 1065	State	Required Resources Agency to supervise(California Water Code supplementation of specified flood control and 12306,12307; amendments to levee projects, enter into a Memorandum of Budget Act of 1991) Understanding with other agencies regarding coordination and mitigation enforcement, and report annually to the legislature regarding project plans. Increased funding for the Delta Flood Protection Fund to $12 million and changed related appropriations. Required Resources Agency to annually assess whether cumulative effect of funded projects has resulted in no net long-term loss of riparian, wildlife, or fisheries habitat, and to take steps necessary to correct deficiencies causing net long-term losses.
1992	Delta Protection Act of 1992	State	Established the Delta Protection Commission, which is to develop a comprehensive, long-term resources management plan for the Delta by July 1, 1994. A basic goal of the Act is to improve flood protection by structural and nonstructural means to ensure an increased level of public health and safety.
1996	Safe, Clean, Reliable Water Supply Act	State	Provided continuous appropriation of (California Water Code §§ 78540-78545; 78686.10-78686.12) $12.5 million for local assistance under the Delta levees subvention program; and $12.5 million for special flood control projects for eight western Delta islands and other Delta locations. Requires Department of Fish & Game review, and their approval of plans consistent with a net long-term habitat improvement plan in the Delta prior to allocating expenditures. Created Flood Control and Prevention Account, and transferred $60 million to the account for pro rata allocation to various flood control projects.
1996	Water Resources Development Act	Federal	Provided emergency supplemental appropriations for recovery from natural disasters, including $4,796,000 construction funds, and $2,694,000 to repair damage caused by floods and other natural disasters. Additional $10 million authorized for the cost-effective emergency acquisition of land and water rights necessitated by floods and other natural disasters.

SOURCES:
DWR 1993, Corps 1993, and DFG and DWR 1997.

Table S-1. Federal and State Statues, Orders, and Regulations Affecting Flood Control (Page 2 of 2)

Levee Stability

Levee conditions in the Delta are unique. In other regions, levees are built to protect land at elevations above normal water levels (BDOC 1993). As continuous water barriers, Delta levees need to be able to withstand flows and stages from daily runoff and tidal cycles, and high flow conditions. Delta levees also must remain fully functional during any improvements or repairs because the levees must continuously protect islands with elevations below sea level, a result of soil subsidence.

Subsidence occurs when levees protect the peat soils of the Delta from inundation. The peat soils dry up, decompose, and partly convert to a gas. This conversion results in a loss of volume in peat soils, which leads to a lowering of interior elevations in the Delta islands while the Delta channels maintain their elevations.

The levees often settle under their own weight on the soft underlying foundation materials. Material has been placed on the crown of the levees periodically to maintain height, while the interiors of the islands get lower over time. Presently, some levee crowns are 20 to 25 feet higher than the interior land surface they protect. In order to maintain stability of these high levee embankments over the relatively soft Delta soils, large berms have been added to widen the base of some levees and to act as a counterbalance to the water in the channels. The ongoing process of land subsidence therefore has created the need for higher and wider levees and berms to protect Delta resources from floods. Table S-2 lists historical inundations of Delta islands.

The stability of a levee depends on the strength of its foundation and its internal strength. Overall, levee system integrity is characterized as the amount of structural and foundation stability of levees. Levee vulnerability refers to a reduced level of integrity. Decreases in levee system integrity often are described as "damage" or "failure." Levee damage refers to situations where the levee has not failed to hold back water but has suffered some decrease in structural integrity. Levee failure refers to situations where a levee has been damaged sufficiently that it has been breached or otherwise has failed to perform its flood protection function.

Levees can fail by three often interrelated mechanisms:

- Overtopping,
- Seepage and piping, and
- Instability.

Overtopping occurs when the stage of the flood water in the channel is greater than the height of the levee. Levee failure results from erosion on the back (land) side of the levee when water cascades over the levee crown and washes away soil until the full cross section is breached.

Levees constructed of clay soil can withstand significantly more overtopping than levees constructed of silty or sandy soil (FEAT 1997). Overtopping can occur not only as a result of flood flows but also as a consequence of high tides and wind (BDOC 1993). Overtopping is of particular concern in the north Delta due to the Mokelumne and Cosumnes rivers and in the west Delta due to tidal influence and wind (BDOC 1993).

Levees can fail through ***seepage and piping***. Some seepage through an earthen levee is common (FEAT 1997). However, when the seepage finds or creates a drainage path, or "pipe" through erodible material,

Islands	Acres Flooded	Year
Andrus Island	7,200	1902, 1907, 1909, 1972
Bacon Island	5,500	1938
Bethel Island	3,400	1907, 1908, 1909, 1911, 1926
Big Break	2,200	1927, remains flooded
Bishop Tract	2,100	1904
Bouldin Island	5,600	1904, 1907, 1908, 1909, 1925
Brack Tract	4,800	1904, 1958
Bradford Island	2,000	1950, 1983
Brannan Island	7,500	1902, 1904, 1907, 1909, 1972
Byron Tract	6,100	1907
Canal Ranch Tract	500	1958
Clifton Court Tract	3,100	1901,1907, remains flooded
Coney Island	900	1907
Dead Horse Island	200	1950 1955, 1980, 1986, 1997
Decker Island	200	1986
Donlon Island	3,000	1937, remains flooded
Empire Tract	3,500	1955
Fabian Tract	6,200	1901, 1906
Fay Island	100	1983
Franks Tract	3,300	1907, 1936, 1938, remains flooded
Glanville Tract		1986
Holland Tract	4,100	1980
Jersey Island	3,400	1900, 1904, 1907, 1908, 1909
Little Franks Tract	350	1981, 1982, 1983 twice, remains flooded
Little Mandeville Island	200	1980, 1982, 1986, 1994, remains flooded
Lower Roberts Island	10,300	1906
Lower Jones Tract	5,700	1907, 1980
Lower Sherman Island	3,200	1907, 1925, remains flooded
Mandeville Island	5,000	1938
McCormack-Williamson Tract	1,500	1938, 1950, 1955, 1958, 1964, 1986, 1997
McDonald Tract	5,800	1982
Medford Island	1,100	1936
Middle Roberts Island	500	1938
Mildred Island	900	1969, 1983, remains flooded
New Hope Tract	2,000 - 9,500	1900, 1904, 1907, 1928, 1986
Palm Tract	2,300	1907
Pescadero Tract	3,000	1938, 1950
Prospect Island	1,100	1980, 1981, 1983 Twice, 1986, 1997
Quimby Island	700	1936, 1938, 1955
Reclamation District 17	4,500 - 5,800	1901, 1911, 1950
Reclamation District 1007	3,000	1925
Rhode Island	100	1938
Ryer Island	11,600	1904, 1907
Sargent-Barnhart Tract	1,100	1904, 1907
Sherman Island	10,000	1904, 1906, 1909, 1969
Shima Tract	2,300	1983 Twice
Shin Kee Tract	700	1938
Staten Island	8,700	1904, 1907
Stewart Tract	3,900	1938, 1950, 1997
Terminous Tract	3,000 - 10,500	1904, 1907
Twitchell Island	3,400	1906, 1907, 1909
Tyler Island	8,700	1904, 1907, 1986
Union Island	24,000	1906
Upper Jones Tract	5,700 - 6,200	1906, 1980
Upper Roberts Island	500	1938
Van Sickle	2,500	1957, 1972, 1980, 1983
Venice Island	3,000	1904, 1906, 1907, 1909, 1932, 1938, 1950, 1982
Victoria Island	7,000	1901, 1907
Webb Tract	5,200	1950, 1980

Table S-2. Historical Inundations of Delta Islands

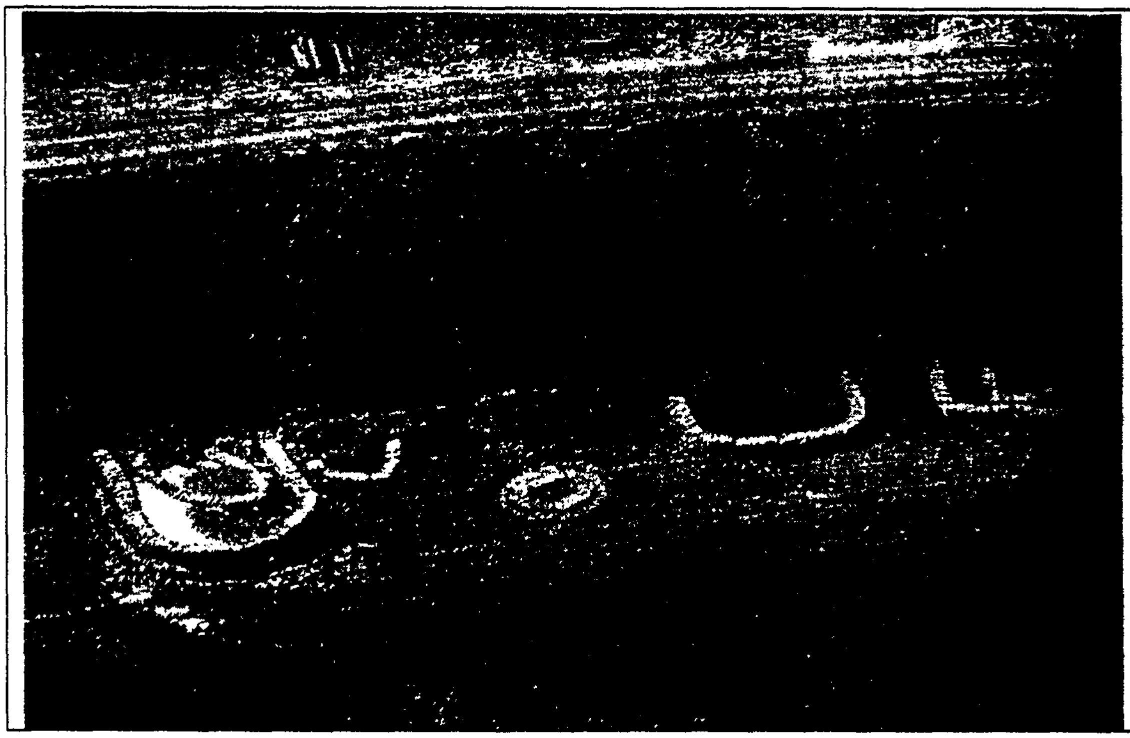

Figure S-1. *Sand Boils Within Sandbag Rings Along the Levee Toe on the Right Bank of the San Joaquin River During the January 1997 Floods*
Source: FEAT 1997

such as sand strata, levee structural material is gradually washed out through a "boil" on the landside of the levee (Figure S-1) (FEAT 1997).

If unchecked, sufficient material can exit the levee through the boil to create a large void inside the levee (FEAT 1997).

The large void weakens the internal structure of the levee and can result in a depression or "slump" in the crown of a levee (FEAT 1997). If the crown slumps below the water surface elevation, overtopping will occur and lead to failure (FEAT 1997).

A levee can fail due to ***instability***. Levee instability can happen when high water velocity or wave action erodes material from the levee or streambank adjacent to the levee, leading to slope instability and increased seepage.

Levees can slip or slough where seepage or thorough saturation from long periods of high water weaken the levee or foundation to the point where the weight of the soil exceeds its internal strength (FEAT 1997).

Several other potential factors can damage and eventually contribute to levee failure, as discussed below.

Erosion. Erosion may be caused by wind-generated waves, currents, tidal action, or boat wakes (BDOC 1993). In some reaches, bank erosion is causing retreat of expendable water-side berms, but in other areas it has proceeded into the levee. Bank retreat measurements in a narrow Delta channel subject to winter flood flows and heavy boat traffic (Georgiana Slough) revealed that over half the observed bank retreat occurred in the nonflood season (primarily from boat wakes) (Limerinos and Smith 1975).

Erosion rates vary in the Delta. Some unprotected banks are not eroding, whereas some Sacramento River banks (in the Delta Region) are eroding at rates up to 4 feet per year, and some slough banks are eroding up to 2 to 3 feet per year (WET 1991). Riprap (rock protection) typically has been used as revetment to control bank erosion (Figure S-2).

Figure S-2. *Riprap Bank Protection*
Source DWR 1990b

Cracks and fissures. Cracks and fissures are a stability problem and provide shorter, unobstructed pathways for piping to occur (BDOC 1993).

Deformation. Deformation may occur where levee foundations are composed of peat or other soft organic soils that have a consistency like toothpaste. If enough pressure is placed on them, the soils might squeeze out from underneath the levee, causing lateral spread (BDOC 1993).

Burrows and roots. Rodent burrows and decaying tree root holes might increase the potential for piping to occur (BDOC 1993).

Dense vegetation. Dense vegetation on levee slopes can make it difficult to detect rodent burrows and root holes (BDOC 1993). Vegetation generally controls erosion; however, continual wave action at normal water levels frequently undercuts vegetation at the waterline and can lead to progressive caving and erosion of the levee slope (BDOC 1993).

The growth or incorporation of vegetation into riprap does not diminish and might strengthen the revetment, as was observed at sites upstream of the Delta along the Sacramento River (WET 1991, Shields 1991).

Encroachment of structures. Encroachment of structures on levee slopes might reduce the protection provided by the levee system and make levee inspection, maintenance, and improvements more difficult (BDOC 1993).

Subsidence. Subsidence is a major concern in the Delta because it increases the water pressure on levees and, therefore, the probability of levee failure and flooding. The U.S. Geological Survey, in cooperation with DWR, evaluated causes of subsidence in the Delta and concluded that reclamation and agricultural activities have caused land subsidence ranging from 1 to 3 inches per year in the Delta (Rojstaczer et al. 1991).

Settlement. Settlement occurs when the construction of Delta levees over soft soils has caused consolidation of their foundations and settlement into the land surface. This settlement occurs at different rates, depending on the variable level of consolidation of the underlying soils at any location along a levee. Levee segments can settle at different rates. This process is generally referred to as differential settlement. Long reaches of Delta levees are therefore subject to differing levels of cracking, seepage, and instability because of differential settlement between adjacent segments of the same continuous levee. To compensate for settlement, material periodically is added to levees to increase their height. The effect of adding materials to levees continues to increase the load on the underlying materials, causing more settlement, and the cycle repeats itself.

Delta levee stability also is affected by seismic hazards. The more prominent faults include the Antioch, Calaveras, Green Valley or Concord, Greenville, Hayward, Rodgers Creek, Sierran Block Boundary Zone (or Winters-Vacaville), and San Andreas (Finch 1992).

Delta levees are constructed of, and are on top of, sand and silt. These materials, when saturated, are known to lose cohesive strength when subjected to the seismic acceleration of an earthquake. This effect is commonly referred to as liquefaction. A recent geotechnical study to assess the potential for liquefaction along the Delta levee system found liquefiable sand to be widespread beneath the levee systems on most of the Delta islands and concluded that the susceptibility of the Delta levees to earthquake-induced liquefaction is high (Finch 1992). If liquefiable soils are at depth or confined beneath the levee, liquefaction might not cause any damage to the levee.

A review of available information indicates that, between 1808 and 1996, approximately 41 earthquakes with magnitudes of 4.5 and above on the Richter Scale occurred in the region within or immediately surrounding the Delta. Five of these historical events had recorded intensities of Modified Mercali Intensity (MMI) VI or greater; however, none are believed to have induced even moderate levels of shaking in the Delta Region. The bedrock and stiff soil sites at the periphery of the Delta have experienced peak accelerations no higher than about 0.lg to 0.15 g (g = acceleration due to gravity) (Working Group 1996). Within the central portions of the Delta, base motions would be expected to have been less than 0.2 g. Even the 1906 San Francisco Earthquake is estimated to have generated peak ground accelerations of 0.08 g or less within most of the Delta Region.

In an effort to estimate probable bedrock motions beneath the Delta within the next 30 years, DWR performed a probabilistic seismic hazard analysis (DWR 1992). The analysis indicated that for a 90% probability of nonexceedance in a 30-year period, peak bedrock accelerations of 0.35 g and 0.15 g were estimated for the western and eastern margins, respectively (DWR 1992)

There is no evidence that a levee in the Sacramento-San Joaquin Delta has ever failed as a result of earthquake shaking. Moreover, there is no evidence of any Delta levee having experienced significant damage as a result of earthquake shaking. The most serious damage in the Delta attributed to an earthquake appears to have been the approximately 3 feet of settlement reported for a Santa Fe Railroad bridge at the Middle River crossing during the 1906 San Francisco Earthquake.

This lack of reported damage, however, does not indicate a seismically strong levee system. The Delta levee system has been in place only a short time relative to the long period typical of large earthquakes. The strongest earthquake loadings probably occurred during the 1868 Hayward and 1906 San .Francisco earthquakes of magnitude 6.8 and 8 on the Richter Scale, respectively. During these events, the levee system was not fully developed (the levees were generally less than half their current height), and the ground accelerations were dampened by the distance to the quake epicenters.

Levee Design Standards

The design standard of Delta levees typically is described as meeting one of the following five general classifications:

None. Little or no freeboard above the 100-year stage;

HMP. Provides 100-year protection with at least 1 foot of freeboard above the 100-year-flood elevation, a minimum crown width of 16 feet, waterside slopes of 1.5 horizontal to 1 vertical, and landside slopes of 2 horizontal to 1 vertical. Reclamation districts must have met this standard by 1991 to receive future federal disaster relief.

Federal Emergency Management Agency (FEMA) 100-year. Provides 100-year protection with at least 3 feet of freeboard above the 100-year flood elevation for urban areas. Minimum crown width is 16 feet. Waterside slopes are 2 horizontal to 1 vertical. FEMA allows variable landside slopes but requires proof of structural stability. Levees that meet these standards qualify landowners for generally lower flood insurance rates and fewer floodplain management restrictions under the National Flood Insurance Program.

Public Law 84-99. Provides 100-year protection with at least 1.5 feet of freeboard above the 100-year-flood elevation and a minimum crown width of 16 feet. Landside slopes vary from 3 horizontal to 1 vertical, to 5 horizontal to 1 vertical, depending on the height of the levee and the depth of peat. Waterside slopes are 2 horizontal to 1 vertical. Levees that meet or exceed Public Law 84-99 design standards qualify for federal post-disaster rehabilitation assistance.

Bulletin 192-82. Provides 300-year flood protection with at least 1.5 feet (agricultural uses) and 3 feet (urban uses) of freeboard above the 300-year-flood elevation. Landside slopes vary from 3 horizontal to 1 vertical, to 7 horizontal to 1 vertical, depending on the height of the levee and the depth of peat. Waterside slopes are two horizontal to one vertical. Levees that meet or exceed Bulletin 192-82 design standards qualify land owners or reclamation districts to receive Delta Levee Subventions Program funds and would allow them to receive Corps certification for Public Law 84-99 funds.

Levee Maintenance

In 1995, DWR inspected and reported on the status of maintenance of flood control levees, channels, and other works operated under cooperative arrangements among federal, state, and local public entities (DWR 1996). This was done under the authority of California Water Code sections 8360, 8370, and 8371, consistent with 33 CFR § 208.10.

Levees were inspected once in spring and once in fall. The inspections verify, for both the Sacramento and San Joaquin River systems, that local agencies are performing their legal and statutory responsibilities (pursuant to Water Code Sections 12642 and 12657) and are meeting their legal obligations, under assurance agreements with the state, to operate and maintain their flood control projects "on any stream flowing into, or in, the Sacramento Valley or the San Joaquin Valley" (DWR 1996).

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DFG. See California Department of Fish and Game.

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GLOSSARY

Crown. Top of a levee.

Erosion. The wearing away of the land surface by various processes, the most important being river currents and waves.

Freeboard. The vertical distance between normal maximum water level; an allowance in protection above the design water surface level. The distance between the elevation of the water surface and the elevation at which overtopping of a levee or spillway will occur.

Hundred-year flood. The probability in any given year of a one in one-hundred flood event.

Hydraulic head. The pressure exerted by water on a unit area because of the height at which the water surface stands above the point where the pressure is determined.

Hydrostatic pressure. The pressure of water at a given depth resulting from the weight of the water above it.

Levee. An embankment, generally constructed close to the banks of a stream, lake, or other body of water, intended to protect the landside from inundation or to confine the streamflow to its regular channel.

Liquefaction. The process in which saturated sandy soil loses cohesion when subject to ground shaking during an earthquake.

Revetment. A facing of stone, concrete, sandbags, or other materials used to protect a bank of earth from erosion; such as riprap.

Seepage. A slow movement of water through permeable soils caused by hydraulic head.

Seismicity. The frequency, intensity, and distribution of earthquake activity in an area.

Settlement. The sinking of levee or berm material into the existing land surface caused by compaction of underlying subsurface soils. Settlement is caused by an increase in the weight of overlying levee fill or berms or by pressure resulting from earth movements.

Stage. The height of the surface of a river above an arbitrary zero point.

Subsidence. The lowering of the land surface near levees. Subsidence results primarily from organic peat soil being converted into a gas. Many Delta islands, especially in the western Delta, are composed of peat soils that decompose when exposed to oxygen and higher temperatures (BDOC 1993). The decomposition process is natural but can be accelerated by agricultural tillage activities that expose a greater surface area of peat soils to oxygen over the same period than nontillage.

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